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Stimulating mathematical communication with SPECOMATSO technology development based on digital literacy

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Abstract

Mathematical communication is crucial in inclusive mathematics teaching and learning to convey mathematical symbols. However, teaching mathematical symbols to deaf students in inclusive classrooms has been a persistent challenge due to the lack of specialized sign language for mathematical expressions. Media, such as SPECOMATSO technology, can serve as a bridge to address this issue. This research focused on developing valid and practical SPECOMATSO technology to strengthen students' literacy and facilitate the delivery of mathematical symbols, which previously posed difficulties for teachers in inclusive settings. The research combined the Alessi & Trollip and V-waterfall models, encompassing seven development stages: analysis, design, implementation, unit testing, integration testing, system testing, and acceptance testing. The research instruments included observation and interview guidelines, a product validation questionnaire, and a student response questionnaire. This study produces SPECOMATSO technology that is valid and practical for learning plane geometry and angles in mathematics. Although this development still needs improvement in fixative abilities, such as storage and editing functions, it is expected to strengthen digital literacy and stimulate mathematical communication among deaf students who face challenges related to their limited auditory capabilities.

Keywords: deaf students; digital literacy; mathematical communication; SPECOMATSO technology

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Introduction

Technological advancements in the 21st century necessitate the development of essential digital skills for effective communication, accessibility, and information analysis. Hence, individuals must be skilled at navigating digital tools and resources and comprehending technology's impact on their personal and professional lives. According to Pratiwi and Pritanova (2017), digital literacy is pivotal in meeting these skill requirements and facilitating individuals' adaptation to new technologies, leading to positive implications. Although on the other side, the negative impact has also stalked the students. With digital literacy, individuals can critically evaluate the credibility and accuracy of online information, enabling them to grasp the full consequences of emerging technologies (Meyers et al., 2013). Consequently, contemporary studies on digital literacy have shifted their focus from concerns about limited digital access to the lack of skills, understanding, and practical experience needed to navigate the constantly evolving digital landscape.

In education, digital literacy has emerged as a crucial skill for 21st-century students, as technology plays an increasingly significant role in their transition to society and the workforce. The importance of digital literacy is a key concern for the Indonesian government, which has taken some measures to enhance citizens' digital literacy through a national program launched in 2021 especially for students (Ratri et al., 2023). This program targets four fundamental pillars of digital literacy: digital ethics, digital safety, digital skills, and digital culture. Government support is evident through regulations and initiatives mandating the inclusion of digital literacy education in school curricula. Numerous studies have demonstrated that integrating digital tools and resources in the classroom can foster improved content learning and increased student engagement in constructing virtual communities, establishing connections, and participating in active academic collaboration (Fewkes & McCabe, 2012; Junco, 2012; Liu et al., 2011; Mehdinezhad, 2011; Pike et al., 2011).

Technology integration in education has demonstrated positive impacts (Haleem et al., 2022). However, it necessitates a certain level of digital literacy for teachers and students. Teachers require the skills and knowledge to effectively incorporate technology into their lessons, while students must be capable of using technology responsibly and ethically (Chodzirin, 2016). Furthermore, there has been a shift in the role of schools, which are now responsible for preparing all learning spaces and continually updating digital literacy skills, understanding, and practice for everyone. According to Asari et al. (2019), Indonesian people have a culture of low technological literacy, which is a challenge for many schools, as several studies have revealed that teachers in Indonesia have low digital literacy. These studies indicate that teachers primarily use digital technology for teaching preparations without considering its broader pedagogical potential (Fitriah, 2017; Liza & Andriyanti, 2020). Moreover, Andriyani, Karim, and Fahmi (2020) asserted that teacher preparation should be designed to encompass a variety of learning instruments with different content, enabling effective and interactive learning. However, the authors also noted that teachers encounter difficulties in designing learning instruments that cater to the needs and characteristics of students, particularly those with special needs.

Deaf students with special needs face challenges due to their limited hearing and communication abilities (Anugerah et al., 2020; Marschark & Spencer, 2007). To overcome their communication barriers, deaf students rely on sign language as a manual mode of communication (Kautsar et al., 2015; Yuniati, 2013). Although the intellectual abilities of deaf students are comparable to those of their regular peers without hearing impairments, the limitations caused by their hearing impairments can impact their mental well-being, social interactions, and knowledge acquisition (Anugerah et al., 2020). This impact is further supported by studies, highlighting the influence of hearing limitations on the emotional, academic, and social adjustment aspects of deaf students (Effendy et al., 2018; Zakia et al., 2016). Often, deaf students face difficulties in expressing their thoughts, leading to mutual understanding challenges.

When designing teaching strategies for deaf students, it is crucial to consider the unique characteristics associated with hearing impairments (Andriyani et al., 2020). While inclusive schools provide equal access to education for deaf students, the differences in their characteristics compared to their hearing peers pose specific challenges, particularly in a subject like mathematics that involves abstract concepts. In an inclusive classroom, where deaf students learn together with their hearing peers, teachers must carefully consider the needs of both deaf and hearing students. This aligns with the findings of Effendy et al. (2018), who emphasized the importance of providing additional support to enhance the focus and engagement of deaf students, similar to other students with disabilities, with sign language playing a critical role in this process.

The reliance on sign language among deaf students poses challenges in the learning process of mathematics. Remarkably, the limitations of sign language in accommodating the entire vocabulary and specific symbols within sign language hinder the conceptual understanding of deaf students (Syafrudin & Sujarwo, 2019). These symbols will be found and play a significant role in mathematics education, as the subject involves logical structures, rigorous rules, and symbols that lack inherent meaning (Soedjadi, 2000). These characteristics of mathematics make it challenging for deaf students to connect abstract mathematical concepts to real-life situations (Beni et al., 2017; Dewayani, 2016).

Numerous researchers have conducted studies highlighting the challenges faced by deaf students in comprehending language and mathematical concepts, primarily on the limitations of sign language in mathematics education (Anditiasari, 2020; Kurniasih et al., 2020; Leton et al., 2021; Linda & Muliasari, 2021). These difficulties were also observed in two inclusive public primary schools in Yogyakarta province. In interviews conducted with mathematics teachers from these schools, it was revealed that deaf students encountered obstacles in fully engaging in mathematics learning. These challenges arise from their struggles in grasping abstract mathematical concepts and the limitations of sign language in representing the symbolic language of mathematics. Moreover, if the mathematics teacher in the inclusive classroom lacks proficiency in sign language as a means of communication for deaf students, additional support is required. Consequently, students need a companion teacher who can interpret the teacher's instructions, as the speed of the teacher's speech may exceed the students' ability to follow.

Mathematical communication, an essential component of mathematics education standards (NCTM, 2000), enables students to articulate, organize, and consolidate their ideas through verbal communication, visual representations, objects, symbols, or body gestures. The limitations of using sign language to convey mathematical symbols present a significant challenge, leading to potential delays in mathematics learning (Krause, 2018). Deaf students often encounter difficulties comprehending instructional materials, resulting in delayed assimilation of the topics discussed in class. Consequently, the expression of mathematical symbols is compromised for these students. Recognizing these challenges, teachers must enhance their instructional practices and receive training on effective representational strategies (Firdaus et al., 2019; Kelly et al., 2002). Additionally, teachers should provide appropriate learning support and utilize supporting tools catering to the unique characteristics and needs of deaf students (Rizki et al., 2018).

Moreover, addressing the limitations of the existing communication device, Rizki et al. (2018) proposed using a technology-based solution called the Portable Sign Language Translator (PSLT), which translates sign language into written messages. However, this technology can only be effective if one of the users has proficiency in sign language, which is not always the case for teachers in inclusive settings. Therefore, other communication support devices needed by deaf students in inclusion settings are a technology for translating spoken language (voice) into text so that deaf individuals understand non-sign language communication without using sign language. Several initiatives have been undertaken to develop speech recognition systems for the deaf, including indoor speech interaction systems based on ZigBee (Qi & Que, 2013), speech recognition-based SIBI or Sistem Isyarat Bahasa Indonesia (Indonesian Language of Sign System) communication designs (Fatjriyatun et al., 2021), and visual-talk introduction systems (Kumar & William, 2021). However, the technologies resulting from these developments only accommodate the need for translation into text in general. They are not yet oriented towards translation into the symbolic language that many students encounter in learning abstract objects such as mathematics. Given the challenges above, there is a need to develop a mathematics learning support technology that facilitates the translation of mathematical symbols and is tailored to communicate mathematical concepts without relying on sign language. Therefore, this research aims to design a speech recognition technology for learning mathematics in inclusive classes with deaf students.

The technology for translating teacher speech in mathematical and symbolic languages developed in this study is the technology for translating teacher speech/voice into real-timely mathematical symbols in mathematics lessons in an inclusive classroom environment which after this is referred to as SPECOMATSO (Speech Recognition for Mathematical Symbols) technology. This technology is developed so that teachers do not need to teach mathematics using sign language in deaf-inclusive classroom settings. Given that not all normal teachers and students in inclusion settings can understand the meaning and use sign language communication (Pandapotan et al., 2023). Moreover, sign language cannot accommodate all common languages (vocabulary), so the vocabulary of deaf students is limited, and their understanding of concepts is hampered, including vocabulary or mathematical symbols (Syafrudin, 2019). This is in line with Sugiarti (2015), who stated limitations in terms of language (vocabulary), can be implicated in difficulties in understanding concepts. This is where SPECOMATSO is needed to bridge the translation of spoken language, which is not sign language, into a mathematical, symbolic language so that students' mathematical vocabulary increases.

Methods

This study employed a Research and Development (R&D) approach, combining the Alessi & Trollip model (Alessi & Trollip, 2001) and the V-waterfall model (Dennis, 2012). In this study, researchers used the Allesi and Trollip model because this model is a particular development model for multimedia products with more concise stages but detailed sub-components at the development stage. Moreover, each type of multimedia has different needs in its development. Even so, this model is weak in the trial procedure, especially in the beta test, considered the final product assessment test. Even though the criteria for the number of test subjects have not been explained in more detail in this test. So, to explore the beta test phase, it is necessary to modify it with the V-waterfall model, which has a clear workflow, especially the clarity and measurability of the series of system workflows and the various subjects involved in it. So that with this model, development can be completed following a predetermined time allocation. In addition, the selection of the V-waterfall development model is also based on the software content contained in the SPECOMATSO technology. The V-waterfall model is a simple development model widely used in software development.

The combination of these two models integrates the planning, design, and development stages from the Alessi and Trollip model with the seven stages of development (analysis, design, implementation/coding, unit testing, integration testing, system testing, acceptance testing) according to the specific requirements of the development research consisting the instruments of test for mathematical communication skills, practicality questionnaires by teachers, observation sheets, interview questionnaires, and expert validator assessment questionnaires. Figure 1 depicts the development research procedures combining the Alessi & Trollip and V-waterfall models.

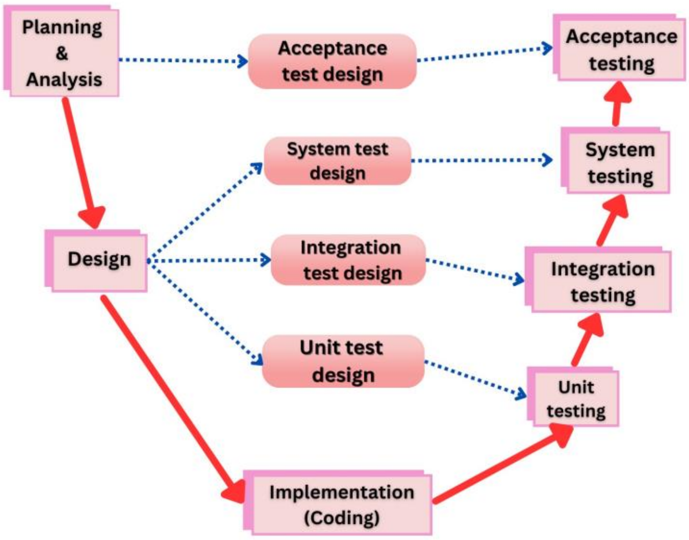

Figure 1. Combination procedure of the Alessi & Trollip model and the V-waterfall model

As illustrated in Figure 1, the development process began with the planning and analysis stages, followed by the design stage. Subsequently, the implementation (coding) stage was undertaken, followed by unit and integration testing. The final stages encompassed system testing/alpha testing and acceptance testing. The outcome of this research is the Speech Recognition for Mathematics Symbol (SPECOMATSO) technology, designed to serve as a supporting tool for mathematics learning in inclusive classrooms at the elementary level, specifically catering to the needs of deaf students. The development of this technology focused on translating teacher speech, particularly for plane geometry and angles. The research was conducted in two Inclusive Elementary Schools in Yogyakarta Province, Elementary School I and II, in Bantul Regency and Yogyakarta Municipality. Inclusive schools are schools that organize learning by identifying regular students with students with special needs in one room.

Data collection in this study involved various methods, including a mathematical communication skills test, interviews, observations, expert validation questionnaires, and student response questionnaires. Interviews and observations were employed to gather insights into the specific requirements of mathematics learning supporting tools from teachers and deaf students. Expert validation questionnaires, administered to two experts and two mathematics teachers, aimed to evaluate the product's feasibility in terms of logical validity, encompassing construct and content aspects. Additionally, a user response questionnaire was administered to two mathematics teachers to assess the practicality of the product.

All questionnaires that became instruments in this study had been tested for validity and reliability so that their feasibility was known to assess what was to be studied. The validity test was conducted to determine whether the research questionnaire was appropriate in measuring the validity and practicality of the learning technology developed in this study. At the same time, the reliability test was conducted to determine whether this research questionnaire could provide consistent results. Based on the results of testing the validity of the questionnaire instrument, it can be seen that all question items have a Product moment person correlation coefficient (r_{xy}) > r_{table} (0.201). Thus, all the questions in the research questionnaire instrument can be declared valid. The reliability test results also show that all variables have a reasonably large Cronbach Alpha, which is above 0.60, so it can be said that all measuring concepts for each variable from the questionnaire are reliable. Therefore, the items in each variable concept are appropriate to be used as a measuring tool.

The researcher conducted a logical validity test to test the validity of the mathematical communication ability test questions. Logical validity was carried out to see the validity of the test questions based on the results of the validator's reasoning. On the validity of each item, the validator tested five questions with two types of questions, so ten questions were tested for validity. The validity test by three validators was carried out for approximately two weeks, and validators immediately gave valid results with an average item validity of 3.27 also suggestions for improvement regarding the legibility of the questions. While the results of the reliability test showed a value of 0.7668, so the questions were said to be reliable.

To examine the mathematical communication skills of deaf students within an inclusive class setting, a mathematical communication skills test was administered. The collected data included both quantitative and qualitative information. Quantitative data were obtained from the results of students' mathematical communication ability tests and the results of practicality questionnaires by the teacher. Qualitative data were obtained from the results of observations, interviews, and the results of the expert validator's assessment questionnaires. Quantitative data in the form of tests were obtained from the results of mathematical communication skills on 50 students and quantitative data on practicality were obtained from 4 product users, namely mathematics teachers. Qualitative data about product validity were obtained from 4 experts, while qualitative data related to interviews and observations were obtained from 50 students.

The data analysis in this study employed a combination of qualitative and quantitative descriptive analysis. The qualitative descriptive analysis technique was used to analyze the responses from the validity questionnaire, focusing on the conformity of the responses with existing theories or provisions. On the other hand, the quantitative descriptive analysis technique was applied to analyze the data collected from the product usability questionnaire. The analysis of the product usability questionnaire involved several steps: determining the average total product usability rating ($\bar{X}$), establishing the ideal average ($\bar{X}_\iota$) and ideal standard deviation (sb_i), and converting the total average rating into a qualitative category based on the categorization guidelines outlined by Widoyoko (2012). The practicality criterion for Speech Recognition for Mathematics Symbols is considered practical if the average rating falls within the minimum practicality score ($102 < \bar{X} \leq 126$).

Results

The research and development results are presented with a discussion, namely the planning and analysis stage, design, implementation/coding, unit testing, integration testing, system testing, and acceptance testing. The description of each of these stages is presented as follows.

Planning and analysis stage

At this planning and analysis stage, the researchers determined the scope of the study related to supporting technology for learning plane geometry and angles. These two materials contain several mathematical symbols that have not been accommodated in sign language or other non-verbal communication. So, it is likely that deaf students are not familiar with these symbols in their informal environment before the elementary school level. Next, the researchers also analyzed to identify the characteristics of prospective users, prepare planning documents, and create a standard product manual. Interviews were conducted with mathematics teachers and deaf students from Elementary Schools I and II. The interviews revealed that teachers faced challenges when representing certain angle symbols, angle units of measurement, and various types of plane geometry with similar shapes when using non-verbal or spoken language for communication. For instance, difficulties were encountered in expressing concepts related to squares, rectangles, degrees, and angles.

When teaching squares and rectangles, teachers must carefully articulate the distinctions between these two shapes to avoid any misconceptions among deaf students. It requires the teacher to deliver the material at a slower pace. However, in inclusive classrooms, teachers must consider the needs of other students who may not require a slower tempo. In sign language, inclusion teachers often encounter challenges in accurately conveying this symbol, leading to multiple interpretations by deaf students. For instance, when teachers form a circle using their thumb and forefinger, deaf students may interpret it as representing 'zero.' Consequently, students may make errors when writing angle units that involve specific angle measurements. Similarly, difficulties arise when representing the degree symbol, which signifies the unit of measurement for angles. The degree symbol, which should be written parallel to the angle measure, may be incorrectly represented. These errors in writing the degree symbol were revealed during interviews, as demonstrated in the sample answers presented in Figure 2.

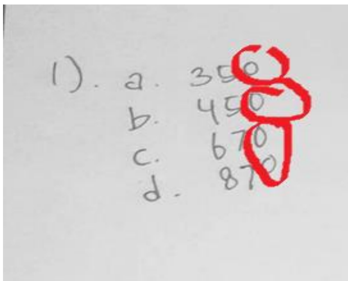

Figure 2. Errors in writing of angle measurement unit symbol

In addition to errors in writing the degree symbol, interviews and observations also revealed misconceptions regarding the term "angle." Many students mistakenly interpret it as referring to the corner of a geometric shape, leading to confusion about the actual definition of an angle and how to correctly write its symbol. It was observed that students frequently write the term "angle" in front of the angle's name, such as "angle ABC." This misconception is evident in students' answers, as illustrated in Figure 3.

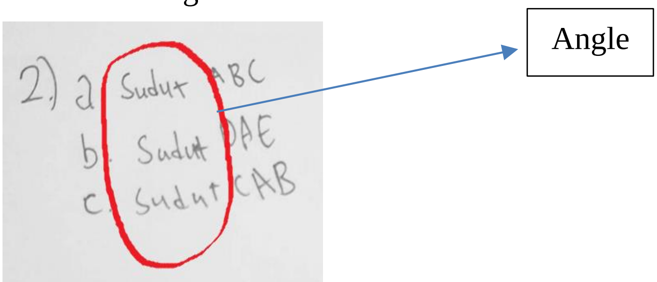

Figure 3. Misconceptions of writing angle names

The findings from interviews and observations revealed that students experienced delays in capturing important information conveyed orally by the teacher, resulting in the loss of crucial details. This further supports the analysis of user characteristics (teachers and deaf students) and helps determine the scope of the technology to be developed for speech recognition into mathematical symbols, focusing on plane geometry and angles. Additionally, the research findings highlighted the misconceptions related to the writing of angle names, further emphasizing the importance of addressing these challenges in developing the technology.

Furthermore, to strengthen the analysis of the characteristics of prospective users, the researchers administered a paper and pencil test to examine mathematical communication skills in terms of mathematical expression, writing, and drawing aspects. The test results show that the mathematical communication skills of deaf students in both schools were poor, with the achievement of the three aspects of mathematical communication of deaf students less than 50% of the maximum score achievement. The average student test result was below 15 (the maximum score =30). The poor students' mathematical communication skills are presented in Figure 4.

Based on the analysis results, the researchers prepared a planning document and a standard product development manual outlining the product specifications based on the identified needs of deaf students and mathematics teachers in inclusive classroom settings. These specifications include the requirement for a teacher speech translator designed explicitly for learning plane geometry and angles, the need for mathematical and symbolic representations, real-time delivery of material by the teacher, storage capability for important material, and communication support tools for teachers to interact with deaf students without relying on sign language and without causing disruptions to other students. At this stage, the researchers designed the response test for prospective users and gathered relevant supporting resources.

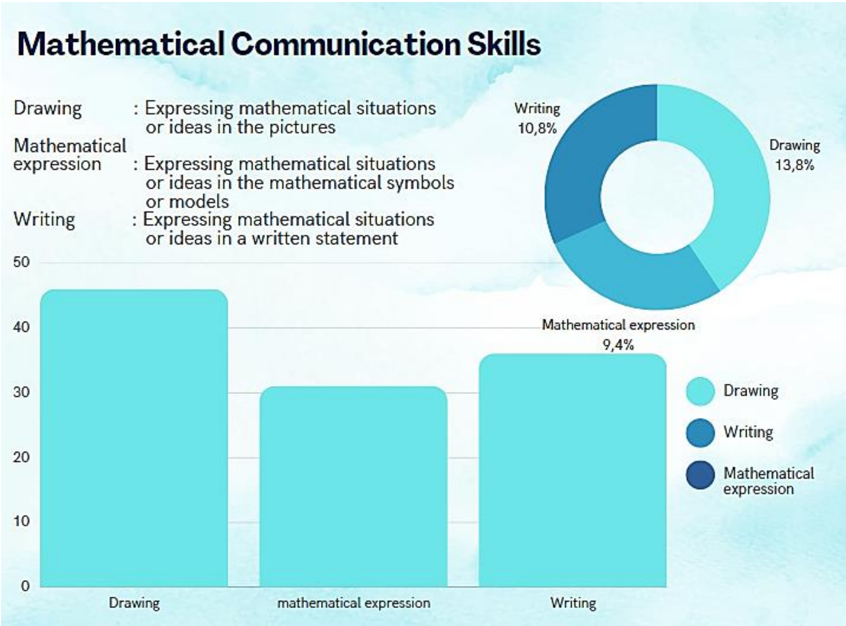

Figure 4. Mathematical communication skills test result

Design stage

In the design stage, speech recognition technology was developed based on the initial idea to address the challenges related to teacher speech translation in mathematical and symbolic language. The design process began with idea development, exploring potential solutions to meet the requirements for an Android-based speech recognition system operating in real-time. The next step involved analyzing the concepts and tasks involved in the development process. Subsequently, a flowchart was created to outline the program structure and sequence. In this stage, the system test design, unit integration test design, and unit test design were also developed to ensure the effectiveness and functionality of the technology.

1. *Implementation (Coding) stage*

This stage aimed to create procedures and functions, develop a GUI (Graphical User Interface), and integrate procedures and functions. The procedures and functions created in this stage were the login procedure, the 'select role' procedure, the 'select class' procedure, the procedure for displaying text and mathematical symbols to the Android device screen, the function of receiving voice, the function of sending voice to the server (Google-Speech-to-Text), the function of receiving voice-to-text conversion results from Google-Speech-to-Text, the function of sending a text to other Android user devices, the function of receiving text messages from the sender, and the function of translating the text into mathematical symbols.

2. *Unit testing stage*

The fourth stage in this development research was testing the developed tool. This test determined whether a unit's procedures and functions were running properly according to design.

3. *Integration testing stage*

All procedures and functions in the units created must be integrated so that the first concept of the system is formed. Next, the combined units were made into a system. At the integration testing stage, the resulting system was a prototype of a teacher's speech translator software in mathematical and symbolic language for learning plane geometry and angles. This software is here in after referred to as SPECOMATSO technology. SPECOMATSO is a technology for translating teacher speech/voice into real-time mathematical symbols in a mathematics lesson in an inclusive class setting. SPECOMATSO framework begins with system input in the form of the teacher's speech, and then the system will change the speech into a word or sentence mathematical symbol. Finally, the existing words/sentences are translated into mathematical symbols. The appearance of the SPECOMATSO technology is presented in Figure 5.

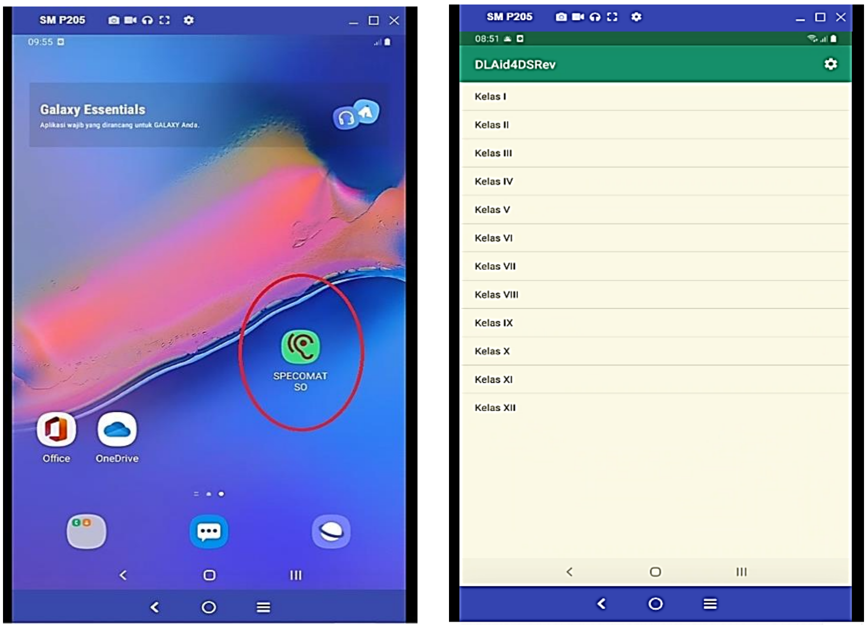

Figure 5. *SPECOMATSO* product developed *(left)*; Select class' menu (*right*)

In this fifth stage, the researchers re-tested whether the combination of procedures and functions and the GUI could run well according to the design. This test was carried out through a development tool to determine whether the teacher's speech signals when conveying plane geometry and angles can be translated into a mathematical symbol. Figure 6 presents an example of the materials presented through the teacher's speech signals translated into mathematical symbols via the android device of the student.

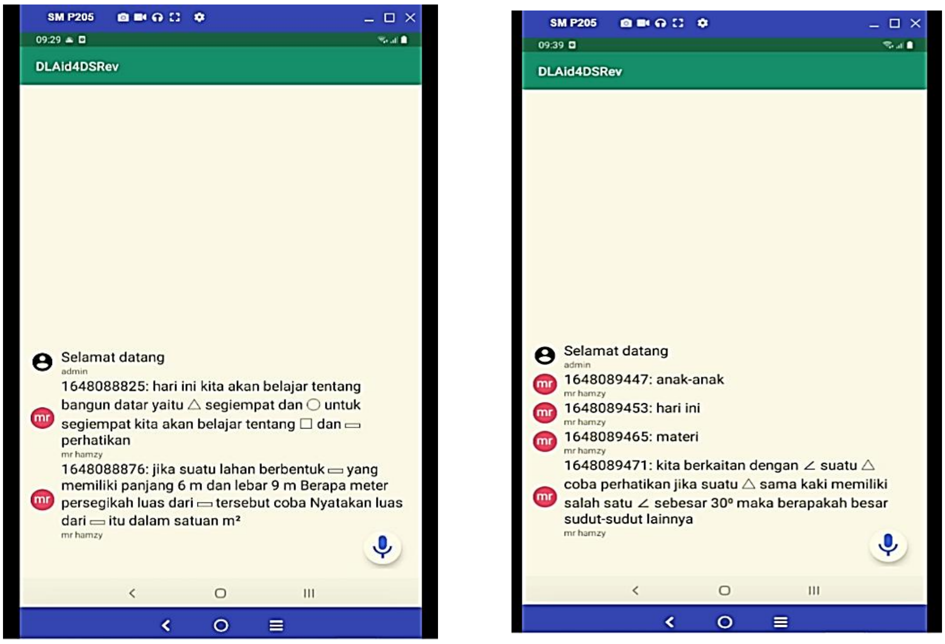

Figure 6. Presentation of plane geometry translated symbolically (*left*); Presentation of angles symbolically translated (*right*)

System testing stage

In the sixth stage, the integrated units of the SPECOMATSO system or technology underwent a validity test conducted by experts and practitioners experienced in the field/school. This stage, also known as the initial alpha stage or main testing, involves evaluating the product's content, flow, and durability. The validity of the developed SPECOMATSO technology was assessed based on the feedback and evaluation provided by two experts and two mathematics teachers. The first expert is a professor at Ahmad Dahlan University, specializing in educational technology. The second expert is a lecturer in informatics engineering at the same university. The other two experts are mathematics teachers, with expertise in teaching students with special needs, particularly those who are deaf or hearing-impaired. Table 1 presents validation assessment by the experts and mathematics teachers.

Table 1. The validation results of SPECOMATSO

Assessment Aspects	Validator 1	Validator 2	Validator 3	Validator 4	Conclusion
Convenience	Appropriate	Appropriate	Appropriate	Appropriate	*Valid*
Suitability	Appropriate	Appropriate	Appropriate	Appropriate	*Valid*
Flexibility	Appropriate	Appropriate	Appropriate	Appropriate	*Valid*
Comprehensiveness	Inappropriate	Inappropriate	Inappropriate	Inappropriate	*In valid*

Table 1 presents the validation results of the SPECOMATSO technology, indicating four validators provided valid ratings regarding convenience, suitability, and flexibility. However, regarding comprehensiveness, the technology did not meet the valid assessment due to the absence of storage and editing menus for data management. As a result, the validators suggested that the researchers re-develop the system by incorporating a data storage menu (considering cellphone storage capacity), an export data feature, an extract menu, and a data editing menu.

The achievement of the three aspects of product validation was demonstrated by the technology's suitability in terms of ease of use and execution, alignment with the learning objectives of understanding mathematical concepts for deaf students without communication constraints, and the flexibility of its design and use in real-time learning settings and inclusive environments.

Acceptance testing stage

The final stage of the SPECOMATSO technology development was the final alpha testing, examining the impact of the technology on the user's affective aspects, the level of interactivity between the user and the developed product, navigation encompassing system orientation, and features on data management and potential user scenarios when entering and exiting the system. To assess these factors, a questionnaire on technology usage was administered to prospective users, specifically mathematics teachers. Table 2 illustrates the results of the usability assessment of the SPECOMATSO technology based on feedback from mathematics teachers.

Table 2. The results of technology practicality of SPECOMATSO

Assessment aspects	Prospective User (CU) 1	Prospective User (CU) 2	Prospective User (CU) 3	Prospective User (CU) 4
Utility	38	35	33	33
Ease of use	52	52	41	47
Ease of learning	20	20	16	16
Satisfaction	35	35	30	28
Mean	145	142	120	124
Total mean	**132.75** (Highly practical)			

Table 2 demonstrates that the average assessment of technology utility by two prospective users falls within the "highly practical" category, with scores exceeding 126. On the other hand, the average assessment by the other two prospective users falls within the "practical" category, with scores ranging between 102 and 126. Consequently, the evaluation from all four prospective users indicates that the product is "practical" in terms of utility, ease of use, ease of learning, and satisfaction. The overall average rating reached 132.75, suggesting a predominantly positive assessment of SPECOMATSO technology usage. Therefore, the prospective users' evaluation regarding learning using SPECOMATSO as a supportive learning medium yielded positive result, indicating a highly practical product.

Discussion

In the context of learning, the selection of appropriate instructional media encompasses several crucial aspects, such as aligning with learning goals and objectives, facilitating ease of use and acquisition, being compatible with the learning environment, and effectively conveying the intended message (Arsyad, 2011; Asyhar, 2012). The findings of this study indicate that the expert assessment of SPECOMATSO technology showed valid results for convenience, suitability, and flexibility. This is because SPECOMATSO technology addresses the need to convey mathematical materials containing symbols that are not fully accommodated in the sign language used by deaf students. Its relevance becomes more apparent when considering the limitations of mathematics teachers in inclusive classrooms who may struggle with sign language and rely solely on spoken language to deliver mathematical content. Moreover, as per the expert assessment, SPECOMATSO technology is user-friendly and caters to the specific challenges faced by deaf students in inclusive settings when trying to follow the teacher's oral explanations, particularly when the pace or inclusion of mathematical symbols poses difficulties. Hence, using teacher speech translation technology, transforming speech into text or mathematical symbols without relying on sign language, introduces a novel approach for deaf students in inclusive classroom settings. Therefore, incorporating SPECOMATSO technology in mathematics learning within inclusive classrooms fulfills several vital criteria of effective instructional media, as acknowledged by the validators.

Using SPECOMATSO technology as a learning tool for mathematics in inclusive classrooms yields positive outcomes by facilitating the communication of mathematical content containing symbols and promoting direct interaction between teachers and deaf students. This aligns with Arsyad (2011), arguing that learning media can expedite learning by overcoming sensory, spatial, and temporal limitations between students and teachers. Effective instructional media can also enhance the clarity of message delivery and information transmission from teachers, which was previously challenging to communicate, thereby fostering direct interaction between students and their learning environment through shared experiences. With the integration of SPECOMATSO technology, both deaf and non-deaf students can engage in simultaneous learning experiences within the same inclusive classroom, regardless of their differences.

In relation to these advantages, SPECOMATSO technology successfully met the practical criteria. The outcomes of the questionnaire administered to assess the feedback of mathematics teachers following the trial activity of using SPECOMATSO technology demonstrated their strong agreement with positive statements regarding usability, user-friendliness, ease of learning, and overall satisfaction with the technology. The positive response from the mathematics teachers signifies that SPECOMATSO technology can serve as an alternative teaching tool in implementing innovative information and communication technology in mathematics instruction. Using technology and information in instructional management aligns with the practical application of Technological Pedagogical Content Knowledge (TPACK), serving as a framework for integrating technology into the learning process (Yeh et al., 2014).

In addition, Januszewski and Molenda (2013) argued that technology can enhance student performance by providing experiences focusing on improving understanding and memory retention, which are typically stored in the memory. Building on this perspective, the implementation of SPECOMATSO technology has the potential to enhance student performance, particularly in the mathematical communication skills of deaf students. Through this technology, deaf students are expected to improve their ability to express mathematical concepts using symbols or mathematical models to solve mathematical problems. SPECOMATSO technology offers a unique learning experience for deaf students, supporting the development of their mathematical communication skills. Furthermore, the use of technology to convey students' mathematical ideas can also foster their digital literacy, enabling them to effectively utilize technology and presenting opportunities for more interactive and engaging forms of mathematical communication.

The effect of using technology in learning shows the significant role of technology in students' communication through digitizing various learning tools. Moreover, learning in exceptional schools that are intended for deaf students who have hearing and communication difficulties. Limited learning time at school and teaching materials that tend to be textual often affect the learning motivation of deaf students who need access to different educational services (Buliali et al., 2022). In the education of deaf students, more attention is required, and an adaptive learning paradigm so can improve the quality of their learning (Adler et al., 2014). Therefore, various learning tools and supporting media must facilitate the needs and accommodate the unique characteristics of deaf students who depend more on vision in communicating and obtaining information during learning (Hasanah et al., 2017; Marschark et al., 2017). The device or media must be oriented toward the device's effectiveness in student communication which has been an obstacle in interacting at a learning time. In this case, communication support devices and media can be smartphone-based, like SPECOMATSO technology. With the use of smartphones in education, it is hoped that student motivation and learning outcomes can further increase because the obstacles can be minimized (Setyaningrum & Waryanto, 2018).

In addition to its advantages, this research also acknowledges certain limitations. One of the limitations is related to the comprehensiveness aspect of the developed technology product, particularly in storing and modifying objects/data. Due to the time-consuming nature of translating teacher speech into mathematical symbols, the research team was unable to incorporate the validator's suggestions regarding the addition of storage and editing menus. These suggestions require further investigation, considering the diverse storage capacities of students' mobile phones. Therefore, including these menus serves as a recommendation for future research. The incompleteness in terms of storage and editing menus within the SPECOMATSO technology represents a shortcoming of this study, as it does not fully fulfill the requirements of a comprehensive learning medium (Asyhar, 2012). Nevertheless, the research findings demonstrate the positive impact of SPECOMATSO technology on communication and interaction between deaf teachers and students during mathematics learning in inclusive classroom settings. To address this limitation, future research should focus on developing storage and editing menus to enhance the fixative capabilities of SPECOMATSO technology as a mathematics learning medium in inclusive classrooms with deaf students.

Conclusion

The SPECOMATSO technology developed successfully meets valid and practical criteria. Its validity is supported by the assessment of four experts, categorizing it as valid in terms of convenience, suitability, and flexibility. However, in terms of comprehensiveness, it falls short of meeting the valid assessment as it lacks storage and editing menus. On the other hand, the practicality of SPECOMATSO technology is demonstrated through the positive response of four prospective users, specifically mathematics teachers from Inclusive Elementary Schools. They rated the technology as highly practical for teaching mathematics in inclusive classrooms with deaf students. These findings indicate that the SPECOMATSO technology effectively facilitates direct communication and interaction between teachers and deaf students, addressing their mathematics learning challenges.

In this case, the SPECOMATSO technology is an alternative means to convey mathematical concepts, particularly those involving symbols not fully accommodated by sign language. Furthermore, SPECOMATSO technology is expected to enhance digital literacy and promote the mathematical communication skills of deaf students. Schools can leverage SPECOMATSO technology or similar technologies to fulfill the objectives of mathematics education in inclusive classrooms, catering to students with diverse characteristics. Future research endeavors should focus on the further development of storage and editing functions, as well as investigating the practicality of SPECOMATSO technology through student assessments and assessing its effectiveness in enhancing the mathematical communication of deaf students.

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Conflicts of Interest

The authors declare no conflict of interest regarding the publication of this manuscript. In addition, the ethical issues, including plagiarism, misconduct, data fabrication and/or falsification, double publication and/or submission, and redundancies, have been completed by the authors.

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Author Contributions

Andriyani: conceptualization & design, acquisition of data, analysis & interpretation of data, writing/drafting the article, review, and editing; **Meita Fitrianawati**: acquisition of data, analysis & interpretation of data, drafting the article, review, and editing; **Ibrahim Alhussain Khalil**: review; **Muya Barida**: acquisition of data, analysis & interpretation of data, drafting the article, and review; **Rully Charitas Indra Prahmana**: review and editing.

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